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Earthen Membrane Microbial Fuel Cell in Septage Treatment

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Abstract

In this study, there was an attempt has been made to create a cost-effective Microbial fuel cell (MFC) constructed with earthen layer as membrane without involving any costly membrane. Practically, operational conditions for those devices require that activity at the anodes is not affected by the ability of the cathode to exchange ion to the cathodic chamber. Therefore, suitable anode to cathode ratios was determined based on MFC performance in both electricity and septage treatment. Those ratios were 4.5, 3, 2.25, 1.8 and 1,5 which were equivalent to the number of anode graphite wires (GWs) of 9 and the cathode graphite wires of 2, 3, 4, 5 and 6, respectively. MFC units were loaded at 0.26 $kgCOD{\cdot}m^{-3}{\cdot}day^{-1}$, corresponded to a hydraulic retention time (HRT) of 14h. The maximum power output of 7.01 ± 1.03$W{\cdot}m^{-3}$ at an external resistance of 100Ω was generated in MFC unit with the ratio of 3.

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Keywords: carbon graphite wires, anode to cathode ratio, V-shaped configuration, Internal resistance.

1. Introduction

In recent years, the energy crisis has become the most important issue all over the world, which requires scientists and researchers to look for replacement of fossil fuel. For this reason, it is necessary to find out other alternatives and renewable energy sources such as wind, solar and hydropower. Moreover, there is a serious increase in wastewater pollution affecting to human life, especially for people who live in remotes areas. Microbial fuel cell (MFC) is considered as a promising technology for wastewater treatment with additional benefit of energy generation [1]. In general, micro-organisms in MFC extracts electric current from a wide range of soluble or dissolved complex organic waste and renewable biomass under anaerobic condition. A large number of substrates have been provided as feed such as glucose [2], brewery waste [3], potato processing waste [4], starch industry waste [5], and domestic waste [6], etc. Although MFC

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was proven to have ability for electricity generation and wastewater treatment, the scale-up of the MFC still remains as a critical issue. The capital cost to develop such a system is for concern of membrane component is typically accounted a large section of budget and responsible for internal resistance of MFC unit. Due to a high cost of Nafion membrane which is used commonly in fuel cell, earthen material was used as substitution [7] [8] [9, 10]. In this study, a MFC was constructed with an earthen membrane in V-shaped configuration without using the commercially available expensive membrane. The earthen membrane has been applied as the medium for proton exchange membrane and making available cathode chamber for MFC.

2. Methodology

2.1 Construction

MFC reactors were constructed using an 8 cm (or 3 inch) cylindrical PVC pipe with a length of 78 cm (see Fig. 1). Working volume of anodic chamber was approximately 2L. The reactors were placed horizontally and cut on the top surface so that V-shape earthen membrane can be installed. This created the two chambers of MFC: anode chamber within cylindrical PVC pipe and cathode chamber on top of the V-shape earthen membrane. Dimensions of earthen materials were in length 66 cm, in width 5 cm and in thickness 4 mm. Carbon graphite wires (GWs) were applied as both cathode and anode materials. Four different cathode surface areas made of 2 GWs (2W-MFC), 3 GWs (3W-MFC), 4 GWs (4W-MFC) and 5 GWs (5W-MFC) were compared while maintaining a constant anode surface area of 9 GWs (projected area approximately 5.49 cm^2). The electrodes surface area ratio (anode/cathode), these ratio were estimated to be 4.5, 3, 2.25 and 1.8 for 2 wires, 3 wires, 4 wires and 5 wires as cathode, respectively.

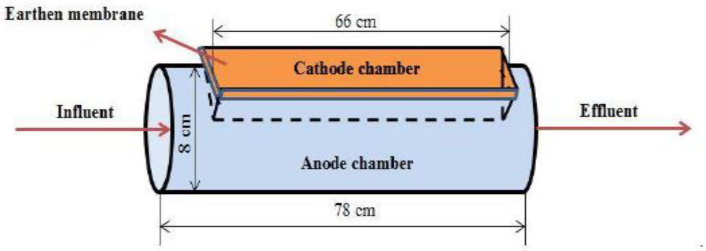

Fig. 1. Schematic of MFC using earthen material as proton exchange membrane.

2.2 MFC operation

Anaerobic sludge was obtained from the anaerobic digester of Nonthaburi municipality, Thailand. The seed sludge was 1L. These reactors were fed intermittently using septage from Sirindhorn International Institute of Technology (SIIT), Thailand. Organic loading rate (OLR) of 0.26 $kgCOD{\cdot}m^{-3}{\cdot}day$ and HRT of 14h. COD concentration of the septage ranged from 150 to 200 mg/L and pH in range of 7.3-7.4. Tap water was used as catholyte and refilled regularly to maintain level. The whole system was placed outdoor with temperature varying from 26 to 34°C. Duplicated experiment and analysis were performed for each variation of cathode surface area.

2.3 Analysis and Calculation

The open circuit voltage (OCV) and current were measured using electrical meter and data were recorded daily. OCV and current were converted to power according to the relationship: $P = IV$, where P = power (mW), I = current (mA) and V = voltage (V). Power density and power per unit volume were calculated by normalizing power to anode surface area and net liquid volume of anode compartment, respectively. pH results were collected by pH meter. Influent and effluent COD concentrations were monitored according to APHA Standard Methods for wastewater treatment [11]. Polarization curves and IV curves were carried out by varying the external resistances from 8,200 to 1Ω and the internal resistance was determined from the slope of line from the plot of voltage versus current.

3. Result and discussion

3.1 Polarization curve and internal resistance

The MFC unit with ratio of 3 generated a maximum volumetric power (normalized to the working volume of anode chamber) of 7.01 ± 1.03 $W \cdot m^{-3}$ (at 16.69 ± 1.90 $A \cdot m^{-3}$ and 499 ± 23 mV) at 100Ω external resistance (Fig. 2). The power generation increased in the MFC with an increase of GWs as cathode. The volumetric power generation for the ratio of 3 was 1.29, 3.08, 2.15 and 3.13 times higher than that of ratios of 4.5, 2.25, 1.8 and 1.5, respectively. The internal resistances determined based on polarization curves were 121 ± 18, 94 ± 2, 146 ± 29, 107 ± 21 and 100 ± 2 (Ω) in ratio of 4.5, 3, 2.25, 1.8 and 1.5, respectively. In an ideal cell, size of electrode will not affect voltage, since this is determined by the properties of the electrodes. Since many factors might also limit the current in the cell. In this study, there was no clear increase of current in relation to cathode surface area.

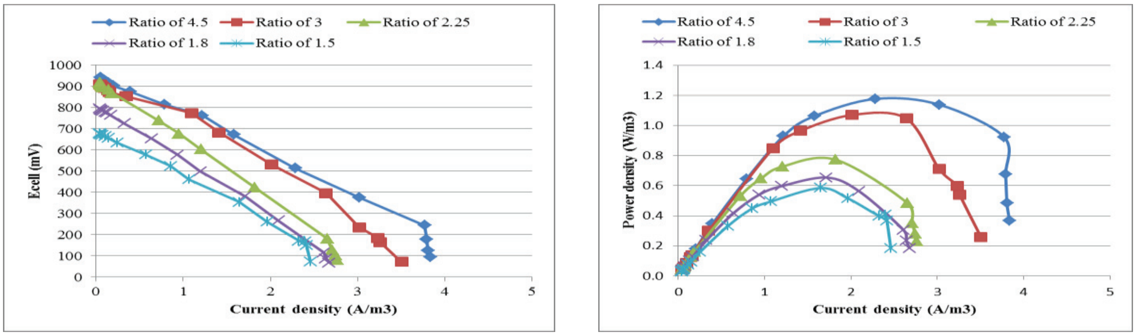

Fig. 2. IV curves (left side) and Polarization curves (right side) of MFC with different electrodes ratios at OLR of 0.26 $kgCOD \cdot m^{-3} \cdot day^{-1}$.

When an evaluation of the polarization curves was carried out (Fig.3), a clear trend of the polarization curves at cell voltage about 800 mV was observed. This situation associated with mass transfer or ions exchange limitation happened during polarization lowered resulted in a less change of the current generation. The MFC units with ratio of 3 and 4.5 appeared to suffer less from this change of the current of 3.51 $A \cdot m^{-3}$ and 3.84 $A \cdot m^{-3}$, respectively.

Table 1. Power generation measured for different electrodes ratios at OLR of 0.26 $kgCOD \cdot m^{-3} \cdot day^{-1}$

Items	Ratio of 4.5	Ratio of 3	Ratio of 2.25	Ratio of 1.8	Ratio of 1.5
Average current (mA)	10.46 ± 1.09	16.69 ± 1.90	6.22 ± 1.01	8.91 ± 0.87	7.66 ± 0.83
Average OCV (mV)	932 ± 46	941 ± 43	910 ± 54	905 ± 45	725 ± 35
Power density ($W \cdot m^{-3}$)	5.44 ± 0.65	7.01 ± 1.03	2.28 ± 0.47	3.26 ± 0.44	2.24 ± 0.33

3.2 Organic matter removal

As organic matter oxidized and electrons releases, the current evolves which leads a general expectation that current should be relative to organic matter removal. However, in this study, there is no clear relation obtained as indicated in Fig. 4. Within the cathode surface area investigated, COD removal was in a range of 41 to 56 %. The highest COD removal was obtained at the anode to cathode ratio of 1.5 with a near minimum current of 7.66 ± 0.83 mA while the highest current was obtained at ratio of 3 with COD removal of 45 – 48%. The reason for this case is still unclear. It was assumed that might be associated with a daily change of septage characteristics due to some reasonable factors (e.g. types and frequency of toilet usage, dietary of toilet user, the amount of water use). Moreover, inorganic matters could lead to the simultaneous oxidation and release the electrons.

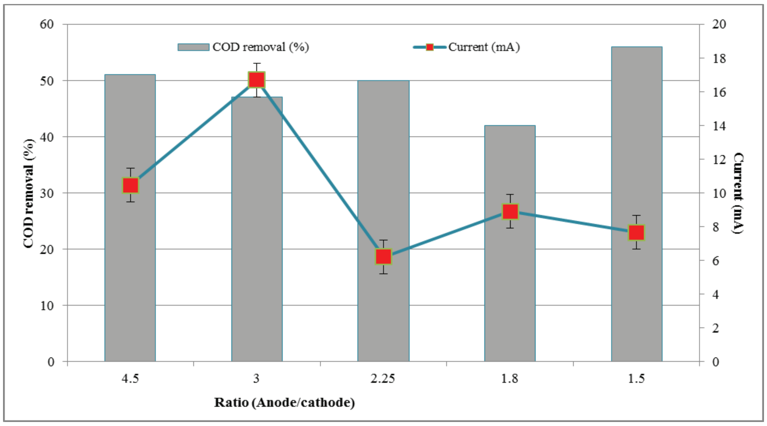

Fig. 3 Correlation between current generation (mA) and COD removal (%)

According to that result, an increase of cathode surface area did not result in an increase of COD removal efficiency. Electricity was produced but it was found that a large part of the organic matter in the septage was removed by bacteria community that did not generate electricity or oxygen diffusion into anodic chamber. Due to that reason, the increase of the organic matter compounds that is converted into electricity needs enhancing by further study.

4. Conclusion

The earthen membrane was used as a medium for proton exchange and cathode chamber in this study. This low cost membrane material can be applied instead of commercially expensive membranes. The cathode surface area was revealed as an impact on MFC performance but the tendency was unclear as there are many factors involved. However, in this study, the increase cathode surface area would not be the way to reduce the internal resistance and enhance performance as expected.

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